Review 4U: Units 3 and 4 (25 questions with detailed solutions)

1. Determine the amount of energy evolved in each of the following situations:

a) 5.0 g of hydrogen gas was heated from 18˚C to 25˚C. The specific heat capacity of hydrogen gas is 14.3 J/g˚C

b) 5.0 g of mass was converted into energy during a fission reaction.

c) 5.0 g of methane CH_4 gas burns in oxygen according to the following reaction:

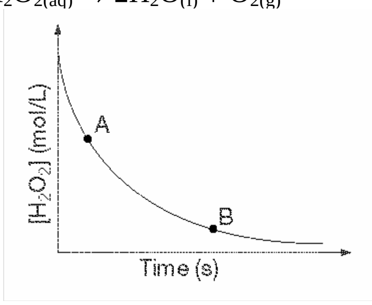
$CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)} + 2\ H_2O_{(g)} + 882\ KJ$

2. Explain why the heat of formation of $I_{2\ (g)}$ is equal to 21KJ/mol and not equal to zero.

3. a) Sketch a graph to show the change in concentration of $CO_{(g)}$, with respect to time, during the following reaction.
$CO_{(g)} + Cl_{2(g)} \rightarrow COCl_{2(g)}$
b) Sketch a graph to show the change in concentration of $COCl_{2(g)}$, with respect to time, during the same reaction.
c) On the first graph, show and explain how you would determine the average rate of reaction.
d) On the first graph, show and explain how you would determine the instantaneous rate of reaction.

4. The forward activation energy of a reaction is 25 kJ/mol, and the heat of reaction is –286.4 kJ/mol.
a) Sketch a potential energy diagram for the reaction. Label the axes, the forward activation energy, the heat of reaction, the transition state, and the reactants and products.
b) Indicate the numerical values of the forward activation energy and the enthalpy change on your diagram.
c) Show and label the effect of a catalyst.

5. The following graph represents the concentration of $H_2O_{2(aq)}$ over time for the decomposition of hydrogen peroxide into water.
$2H_2O_{2(aq)} \rightarrow 2H_2O_{(l)} + O_{2(g)}$



a) What would you do to determine the rate of reaction at A?
b) Compare the rate of reaction at A with the rate of reaction at B. Explain the difference in terms of the collision theory.
c) Sketch the general shape of the curve, showing the concentration of H_2O versus time on the same graph.

6. The experimental data in the table below were collected for the following reaction of nitrogen monoxide and hydrogen. What is the rate law for this reaction?
$2NO_{(g)} + 2H_{2(g)} \rightarrow N_{2(g)} + 2H_2O_{(g)}$

Trial	Initial concentration (mol/L)		Initial rate of disappearance of NO (mol/L•s)
	[NO]	$[H_2]$	
1	0.10	0.10	1.23×10^{-3}
2	0.10	0.20	2.46×10^{-3}
3	0.20	0.10	4.92×10^{-3}

7. Discuss **<u>three factors</u>** that would affect the rate of reaction and explain how it works. Refer to the collision theory or the mechanism of the reaction when applicable

8. Given the following reaction mechanism:
   $2A \rightarrow B + 2C$ (slow)
   $B + C \rightarrow D + E$ (fast)
   $C + D \rightarrow E + F$ (fast)
   a) What is the equation for the overall reaction?
   b) Changing the concentration of which substance(s) would have the most effect on the rate of the overall reaction?
   c) If the mechanism is acceptable, what should be the rate equation for this reaction?
   d) Which substance(s) is/are the intermediates?
   e) Was a catalyst used in this reaction?

9. The following equation represents the decomposition of phosphorus trihydride (phosphine). The initial rate is 2.0×10^{-4} mol/(L•s).
   $4PH_{3(g)} \rightarrow 6H_{2(g)} + P_{4(g)}$
   a) What is the rate of formation of H_2?
   b) What is the rate of formation of P_4?

10. Given equations (1), (2), and (3), calculate the standard enthalpy of formation of acetylene, C_2H_2, as shown in equation (4).
   (1) $C_{(graphite)} + O_{2(g)} \rightarrow CO_{2(g)}$ $\Delta H°_{rxn} = -393.5$ kJ
   (2) $H_{2(g)} + \frac{1}{2}O_{2(g)} \rightarrow H_2O_{(l)}$ $\Delta H°_{rxn} = -285.8$ kJ
   (3) $2C_2H_{2(g)} + 5O_{2(g)} \rightarrow 4CO_{2(g)} + 2H_2O_{(l)}$ $\Delta H°_{rxn} = -2598.8$ kJ
   (4) $2C_{(graphite)} + H_{2(g)} \rightarrow C_2H_{2(g)}$

11. Use standard heats of formation and the following equation to determine the enthalpy of formation of $C_2H_{6(g)}$.
   $2C_2H_{6(g)} + 7O_{2(g)} \rightarrow 4CO_{2(g)} + 6H_2O_{(l)}$ $\Delta H_{rxn} = -3127$ kJ

Review 4U Equilibrium questions:

12. Based on your knowledge of strong and weak acids and bases, is the solution of each salt acidic, basic, or neutral? Explain your choice.
   a) KCN b) Na_2SO_4 c) $CuClO_3$

13. Complete the following table, based on the following equilibrium system.
   $Ni^{2+}_{(aq)} + 6NH_{3(aq)} \Leftrightarrow Ni(NH_3)_6{}^{2+}_{(aq)}$
   green blue

Stress	Colour
addition of nickel(II) nitrate	
removal of ammonia	
addition of water	
addition of inert gas at constant pressure	
removal of $Ni(NH_3)_6{}^{2+}_{(aq)}$	

14. Complete the following table, based on the following equilibrium system.
$3H_{2(g)} + N_{2(g)} \Leftrightarrow 2NH_{3(g)}$ $\Delta H = -92$ kJ

Stress	Equilibrium shift
decrease in volume	
addition of inert gas at constant pressure	
removal of $NH_{3(g)}$	
increase in temperature	

15. Sketch a graph that illustrates the change in pH as a weak base is titrated with a strong acid.

16. 0.150 mol of SO_3 and 0.150 mol of NO are placed in a 1 L container and allowed to react as follows. At equilibrium, the concentration of both SO_2 and NO_2 is 0.0621 mol/L. What is the equilibrium constant?
$SO_{3(g)} + NO_{(g)} \Leftrightarrow SO_{2(g)} + NO_{2(g)}$

17. The following equilibrium system has an equilibrium constant of 0.0202. Find the equilibrium concentrations if 1.50 mol of $HI_{(g)}$ are injected into a 1.00 L flask.
$2HI_{(g)} \Leftrightarrow I_{2(g)} + H_{2(g)}$

18. Lactic acid, $C_3H_6O_3$, builds up in human muscles during anaerobic exercise. If the initial concentration of lactic acid is 0.12 mol/L and the pH is 2.39, what is K_a for lactic acid?

19. Pyridine, C_5H_5N, is an important chemical in the manufacture of medications and vitamins. K_b for pyridine is 1.9×10^{-9}. What is the pH of a solution that has a pyridine concentration of 0.075 mol/L?

20. A solution of hydrocyanic acid has an initial concentration of 5.0×10^{-3} mol/L. What are the concentrations of the ions at equilibrium, if $K_a = 4.9 \times 10^{-10}$.

21. The solubility of calcium fluoride is 1.6×10^{-2} g/L at 20°C. Determine K_{sp} for calcium fluoride.

22. What is the molar solubility of barium fluoride, if K_{sp} for barium fluoride is 1.7×10^{-6}?

23. 250 mL of 2.3×10^{-3} mol/L potassium iodate is reacted with an equal volume of 2.0×10^{-5} mol/L lead(II) nitrate. Will a precipitate of lead(II) iodate ($K_{sp} = 3.2 \times 10^{-13}$) form?

24. 45.0 mL of hydrochloric acid is titrated with 105.3 mL of a 1.00 mol/L solution of lithium hydroxide. What was the concentration of the hydrochloric acid?

25. A 35.0 mL sample of (monoprotic) lactic acid, $C_3H_6O_3$, is titrated with 20.0 mL of a 4.0×10^{-4} mol/L sodium hydroxide solution. What is the pH of the resulting solution at the equivalence point, if K_a for lactic acid is 1.4×10^{-4}?

review energy and rate

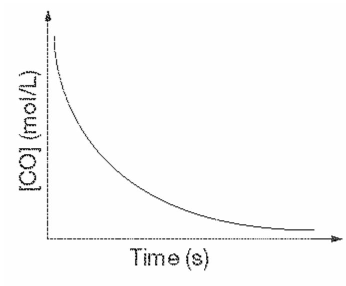
1. a) $Q=mc\Delta T$ $Q= 5.0x10^2 J$ b) $E= mc^2$ $E= 4.5x10^{17}$ J

c) $\frac{\Delta H_1}{n_1} = \frac{\Delta H_2}{n_2}$ Find n_1 first mass/molar mass of CH_4 and Final answer = $-2.7x10^2$ KJ

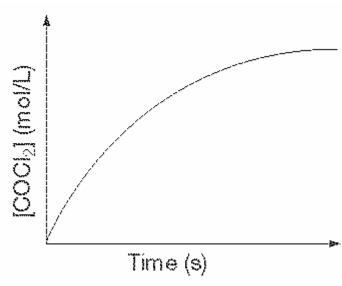
2. I_2 is not found in the gaseous state in nature. (It is solid at room temperature)

3.

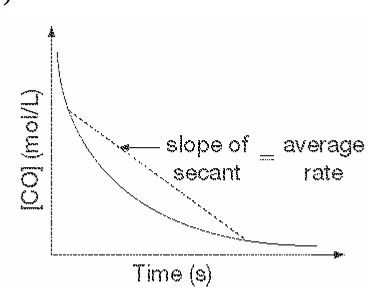
a)



b)

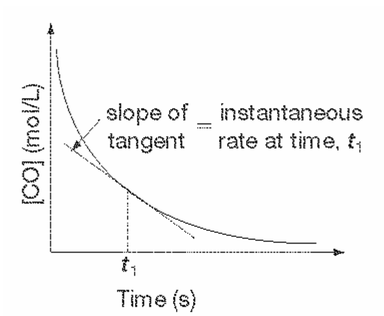


c)



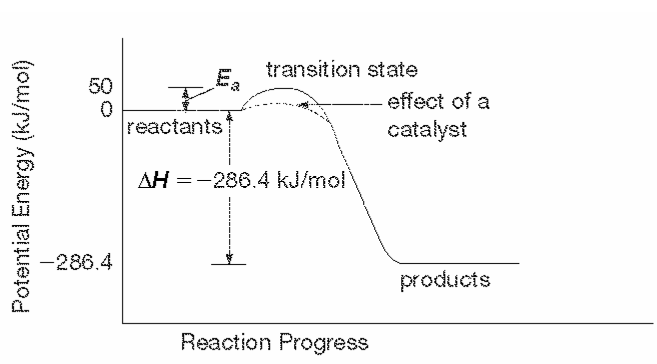
The average rate is determined by drawing the secant to join the beginning of the required time interval to the end of this time interval. The average rate is equal to the slope of the secant.

d)

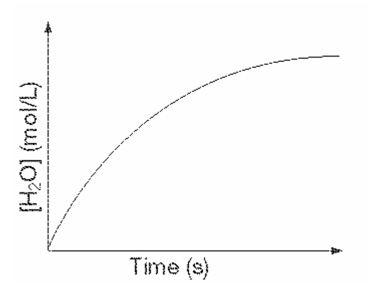


The instantaneous rate is determined by drawing the tangent to the curve at the time for which the instantaneous rate is required. The instantaneous rate is equal to the slope of the tangent.

4.



5c)



5. a) Draw a tangent to the curve at A. Then calculate the slope of the tangent to the curve.

b) The rate of reaction at B is less than the rate of reaction at A. As the reaction proceeds, the concentration of H_2O_2 decreases because it is used up in the reaction. This decrease in concentration results in fewer successful collisions and hence a reduced reaction rate.

6. Compare trials 1 and 2: Doubling the concentration of $H_{2(g)}$ causes the reaction rate to double. Therefore, the reaction rate is first order with respect to the concentration of $H_{2(g)}$.
Compare trials 1 and 3: Doubling the concentration of $NO_{(g)}$ causes the reaction rate to quadruple. Therefore, the reaction rate is second order with respect to $NO_{(g)}$.
Reaction rate = $k[H_{2(g)}]^1[NO_{(g)}]^2$

7. Temperature, catalyst, concentration of reactants, refer to collision theory (notes)

8. a) $2A \rightarrow 2E + F$
b) A since it is the only reactant and also by referring to the slow step.
c) $r=k[A]^2$ based on the rate law of the slow step.
d) B, C and D.
e) No

9. a)

Rate of formation of H_2 = Initial rate for decomposition of PH_3 × Mole ratio of H_2 to PH_3

$$= 2.0 \times 10^{-4}\ \text{mol/(L•s)} \times \frac{6\ \text{mol } H_2}{4\ \text{mol } PH_3}$$

$$= 3.0 \times 10^{-4}\ \text{mol/(L•s)}$$

b)

Rate of formation of P_4 = Initial rate for decomposition of PH_3 × Mole ratio of P_4 to PH_3

$$= 2.0 \times 10^{-4}\ \text{mol/(L•s)} \times \frac{1\ \text{mol } P_4}{4\ \text{mol } PH_3}$$

$$= 3.3 \times 10^{-5}\ \text{mol/(L•s)}$$

10.

$2C_{(graphite)} + 2O_{2(g)} \rightarrow 2CO_{2(g)}$ $\Delta H^\circ_{rxn} = -787.0$ kJ

$2CO_{2(g)} + H_2O_{(l)} \rightarrow C_2H_{2(g)} + \frac{5}{2}O_{2(g)}$ $\Delta H^\circ_{rxn} = 1299.4$ kJ

$H_{2(g)} + \frac{1}{2}O_{2(g)} \rightarrow H_2O_{(l)}$ $\Delta H^\circ_{rxn} = -285.8$ kJ

$2C_{(graphite)} + H_{2(g)} \rightarrow C_2H_{2(g)}$ $\Delta H^\circ_{rxn} = -226.6$ kJ

11.

$\Delta H_{rxn} = [4(\Delta H^\circ_f\ CO_{2(g)} + 6(\Delta H^\circ_f\ H_2O_{(l)})] - [2(\Delta H^\circ_f\ C_2H_{6(g)}) + 7(\Delta H^\circ_f\ O_{2(g)})]$
$-3127\ \text{kJ} = [4(-393.5\ \text{kJ/mol}) + 6(-285.8\ \text{kJ/mol})] - [2(\Delta H^\circ_f\ C_2H_{6(g)}) + 7(0.0\ \text{kJ/mol})]$
$-3127\ \text{kJ} = [(-1574\ \text{kJ}) + (-1714.8\ \text{kJ})] - [2(\Delta H^\circ_f\ C_2H_{6(g)}) + (0\ \text{kJ})]$
$-3127\ \text{kJ} = -3289\ \text{kJ} - 2(\Delta H^\circ_f\ C_2H_{6(g)})$
$161.8\ \text{kJ} = -2(\Delta H^\circ_f\ C_2H_{6(g)})$
$H^\circ_f\ C_2H_{6(g)} = -80.9$ kJ/mol

The heat of reaction for the reaction is –80.9 kJ/mol $C_2H_{6(g}$

12. a) The solution is basic, since KCN is the salt of a strong base and a weak acid.
b) The solution is neutral, since Na_2SO_4 is the salt of a strong base and a strong acid.
c) The solution is acidic, since $CuClO_3$ is the salt of a weak base and a strong acid.

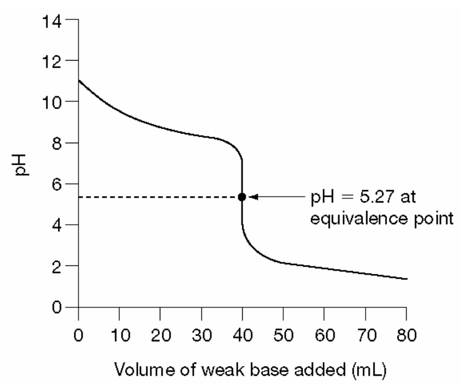
13.

Stress	Colour
addition of nickel (II) nitrate	increase in intensity of blue
removal of ammonia	increase in intensity of green
addition of water	dilution and reduction in intensity of colour
addition of inert gas at constant pressure	no effect
removal of $Ni(NH_3)_6{}^{2+}{}_{(aq)}$	decrease in intensity of green

14

Stress	Equilibrium shift
decrease in volume	to the right
addition of inert gas at constant volume	no effect
removal of $NH_{3(g)}$	to the right
increase in temperature	to the left

15.



16.

Concentration (mol/L)	$SO_{3(g)}$	+	$NO_{(g)}$	$\Leftrightarrow$	$SO_{2(g)}$	+	$NO_{2(g)}$
Initial	0.150		0.150		0.0		0.0
Change	–0.0621		–0.0621		0.0621		0.0621
Final	0.0879		0.0879		0.0621		0.0621

$$K_{eq} = \frac{[NO_2][SO_2]}{[NO][SO_3]}$$

$$= \frac{(0.0621)(0.0621)}{(0.0879)(0.0879)}$$

$$= 4.99 \times 10^{-1}$$

The equilibrium constant is 4.99×10^{-1}.

17..

Concentration (mol/L)	$2HI_{(g)}$	$\Leftrightarrow$	$I_{2(g)}$	+	$H_{2(g)}$
Initial	1.50		0.0		0.0
Change	$-2x$		x		x
Final	$1.50 - 2x$		x		x

$$K_{eq} = \frac{[I_2][H_2]}{[HI]^2}$$
$$= \frac{(x)(x)}{(1.50 - 2x)^2}$$
$$= 0.0202$$

Take the square root of both sides.

$$\frac{x}{1.50 - 2x} = 0.142$$
$$x = 0.142(1.50 - 2x)$$
$$x = 0.213 - 0.284x$$
$$1.284x = 0.213$$
$$x = 0.166 \text{ mol/L}$$

The equilibrium concentrations of $H_{2(g)}$ and $I_{2(g)}$ are both 0.166 mol/L. The equilibrium concentration of $HI_{(g)}$ is 1.50 – 0.332 = 1.17 mol/L.

18.

$$\text{pH} = -\log[H_3O^+_{(aq)}]$$
$$[H_3O^+] = 10^{-\text{pH}}$$
$$= 10^{-2.39}$$
$$= 4.1 \times 10^{-3} \text{ mol/L}$$

Concentration (mol/L)	$C_3H_6O_{3(aq)}$	+	$H_2O_{(l)}$	$\Leftrightarrow$	$H_3O^+_{(aq)}$	+	$C_3H_5O_3^-{}_{(aq)}$
Initial	0.12				0.0		0.0
Change	-4.1×10^{-3}				4.1×10^{-3}		4.1×10^{-3}
Final	0.116				4.1×10^{-3}		4.1×10^{-3}

$$K_a = \frac{[H_3O^+][C_3H_5O_3^-]}{[C_3H_6O_3]}$$
$$= \frac{(4.1 \times 10^{-3})(4.1 \times 10^{-3})}{0.116}$$
$$= 1.45 \times 10^{-4}$$

Therefore, K_a is 1.45×10^{-4}.

19. $C_5H_5N_{(aq)} + H_2O_{(l)} \Leftrightarrow C_5H_6N^+_{(aq)} + OH^-_{(aq)}$

Concentration (mol/L)	$C_5H_5N_{(aq)}$	+	$H_2O_{(l)}$	$\Leftrightarrow$	$C_5H_6N^+_{(aq)}$	+	$OH^-_{(aq)}$
Initial	0.075				0.0		0.0
Change	$-x$				x		x
Final	$0.075 - x$				x		x

$$K_b = \frac{[C_5H_6N^+][OH^-]}{[C_5H_5N]}$$
$$= \frac{x^2}{0.075 - x}$$
$$= 1.9 \times 10^{-9}$$

Since x is very small, use an approximation.

$$\frac{x^2}{0.075} = 1.9 \times 10^{-9}$$
$$x^2 = 1.425 \times 10^{-10}$$
$$x = 1.19 \times 10^{-5}$$

The equilibrium concentration of $OH^-_{(aq)}$ is 1.19×10^{-5} mol/L.

$$pOH = -\log[OH^-]$$
$$= -\log(1.19 \times 10^{-5})$$
$$= 4.92$$
$$pH = 14 - pOH$$
$$= 14 - 4.92$$
$$= 9.08$$

The pH of the solution is 9.08.

20

Concentration (mol/L)	$HCN_{(aq)}$	+	$H_2O_{(l)}$	$\Leftrightarrow$	$H_3O^+_{(aq)}$	+	$CN^{-(aq)}$
Initial	5.0×10^{-3}				0.0		0.0
Change	$-x$				x		x
Final	$(5.0 \times 10^{-3}) - x$				x		x

$$K_a = \frac{[H_3O^+][CN^-]}{[HCN]}$$
$$= \frac{x^2}{(5.0 \times 10^{-3}) - x}$$
$$= 4.9 \times 10^{-10}$$

Since x is very small, use an approximation.

$$\frac{x^2}{5.0 \times 10^{-3}} = 4.9 \times 10^{-10}$$
$$x^2 = 2.45 \times 10^{-12}$$
$$x = 1.6 \times 10^{-6}$$

The equilibrium concentrations of $H_3O^+_{(aq)}$ and $CN^-_{(aq)}$ are 1.6×10^{-6} mol/L. The equilibrium concentration of $HCN_{(aq)}$ is 5.0×10^{-3} mol/L.

21.

$CaF_{2(s)} \Leftrightarrow Ca^{2+}_{(aq)} + 2F^{-}_{(aq)}$

$K_{sp} = [Ca^{2+}_{(aq)}][F^{-}_{(aq)}]^2$

$$[CaF_{2(s)}] = \frac{1.6 \times 10^{-2}\ \text{g/L}}{78.01\ \text{g/mol}}$$

$= 2.05 \times 10^{-4}$ mol/L

$[Ca^{2+}_{(aq)}] = [CaF_{2(s)}] = 2.05 \times 10^{-4}$ mol/L

$[F^{-}_{(aq)}] = 2[CaF_{2(s)}]$

$= 2(2.05 \times 10^{-4}$ mol/L)

$= 4.10 \times 10^{-4}$ mol/L

$K_{sp} = [Ca^{2+}_{(aq)}][F^{-}_{(aq)}]^2$

$= (2.05 \times 10^{-4}$ mol/L$)(4.10 \times 10^{-4}$ mol/L$)^2$

$= 3.45 \times 10^{-12}$

Therefore, K_{sp} for calcium fluoride is 3.45×10^{-12}.

22. $BaF_{2(s)} \Leftrightarrow Ba^{2+}_{(aq)} + 2F^{-}_{(aq)}$

$K_{sp} = [Ba^{2+}_{(aq)}][F^{-}_{(aq)}]^2$

Concentration (mol/L)	$BaF_{2(s)} \Leftrightarrow$	$Ba^{2+}_{(aq)}$ +	$2F^{-}_{(aq)}$
Initial	----	0	0
Change	----	x	$2x$
Equilibrium	----	x	$2x$

$K_{sp} = [Ba^{+}_{(aq)}][F^{-}_{(aq)}]^2$

$K_{sp} = (x)(2x)^2$

$1.7 \times 10^{-6} = 4x^3$

$x = 7.5 \times 10^{-3}$ mol/L

The molar solubility of barium fluoride is 7.5×10^{-3} mol/L.

23.

$Pb(IO_3)_{2(s)} \Leftrightarrow Pb^{2+}_{(aq)} + 2IO_3^{-}_{(aq)}$

$$[Pb^{2+}_{(aq)}] = [Pb(NO_3)_{2(aq)}] \times \frac{V_{initial}}{V_{final}}$$

$$= (2.0 \times 10^{-5}\ \text{mol/L}) \times \frac{0.250\ \text{L}}{0.500\ \text{L}}$$

$= 1.0 \times 10^{-5}$ mol/L

$$[IO_3^{-}{}_{(aq)}] = [KIO_{3(aq)}] \times \frac{V_{initial}}{V_{final}}$$

$$= (2.3 \times 10^{-3}\ \text{mol/L}) \times \frac{0.250\ \text{L}}{0.500\ \text{L}}$$

$= 1.15 \times 10^{-3}$ mol/L

$Q_{sp} = [Pb^{2+}_{(aq)}][IO_3^{-}{}_{(aq)}]^2$

$= (1.0 \times 10^{-5}$ mol/L$)(1.15 \times 10^{-3}$ mol/L$)^2$

$= 1.32 \times 10^{-11}$

Since $Q_{sp} > K_{sp}$, $Pb(IO_3)_2$ will precipitate until $Q_{sp} = 3.2 \times 10^{-13}$.

24. $LiOH_{(aq)} + HCl_{(aq)} \Leftrightarrow LiCl_{(aq)} + H_2O_{(l)}$

Moles LiOH = $C \times V$

$= 0.1053 \text{ L} \times 1.00 \text{ mol/L}$

$= 1.053 \times 10^{-1}$ mol

Moles HCl = 1.053×10^{-1} mol LiOH $\times \dfrac{1 \text{ mol HCl}}{1 \text{ mol LiOH}}$

$= 1.053 \times 10^{-1}$

$C_{\text{hydrochloric acid}} = \dfrac{n}{V}$

$= \dfrac{1.053 \times 10^{-1} \text{ mol}}{0.045 \text{ L}}$

$= 2.34$ mol/L

The concentration of the hydrochloric acid was 2.34 mol/L.

25. $C_3H_6O_{3(aq)} + NaOH_{(aq)} \Leftrightarrow NaC_3H_5O_{3(aq)} + H_2O_{(l)}$

Moles NaOH = $0.020 \text{ L} \times (4.0 \times 10^{-4} \text{ mol/L})$

$= 8.0 \times 10^{-6}$ mol

From the one to one ratio, there are 8.0×10^{-6} mol of $NaC_3H_5O_{3(aq)}$.

Total volume = 35.0 mL + 20.0 mL

= 55.0 mL

$[NaC_3H_5O_{3(aq)}] = 8.0 \times 10^{-6}$ mol/0.055 L

$= 1.45 \times 10^{-4}$ mol/L

The salt forms $K^+_{(aq)}$ and $C_3H_5O_3{}^-{}_{(aq)}$ in solution. $K^+_{(aq)}$ is the conjugate acid of a strong base, so it does not react with water. $C_3H_5O_3{}^-{}_{(aq)}$ is the conjugate base of a weak acid, so it does react with water. The pH is determined by the extent of the following reaction.

$C_3H_5O_3{}^-{}_{(aq)} + H_2O_{(l)} \Leftrightarrow C_3H_6O_{3(aq)} + OH^-{}_{(aq)}$

$K_b = \dfrac{K_w}{K_a} = \dfrac{1.0 \times 10^{-14}}{1.4 \times 10^{-4}} = 7.14 \times 10^{-11}$

Since x is very small, the change in $[C_3H_5O_3{}^-{}_{(aq)}]$ can be ignored.

Concentration (mol/L)	$C_3H_5O_3{}^-{}_{(aq)}$	$+ H_2O_{(l)}$	$\Leftrightarrow C_3H_6O_{3(aq)}$	$+ OH^-{}_{(aq)}$
Initial	1.45×10^{-4}		0	0
Change	$-x$		x	x
Equilibrium	$(1.45 \times 10^{-4}) - x \approx 1.45 \times 10^{-4}$		x	x

$$K_b = \frac{[C_3H_6O_{3(aq)}][OH^-{}_{(aq)}]}{[C_3H_5O_3{}^-{}_{(aq)}]}$$

$7.14 \times 10^{-11} = \dfrac{x^2}{1.45 \times 10^{-4}}$

$x^2 = 1.0353 \times 10^{-14}$

$x = 1.0175 \times 10^{-7}$

pOH = $-\log x$

$= -\log(1.0175 \times 10^{-7})$

$= 6.99$

pH = $14 - 6.99$

$= 7.01$

The pH at the equivalence point is 7.01.